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(54) **LOCALIZED POWER POINT OPTIMIZER FOR SOLAR CELL INSTALLATIONS**

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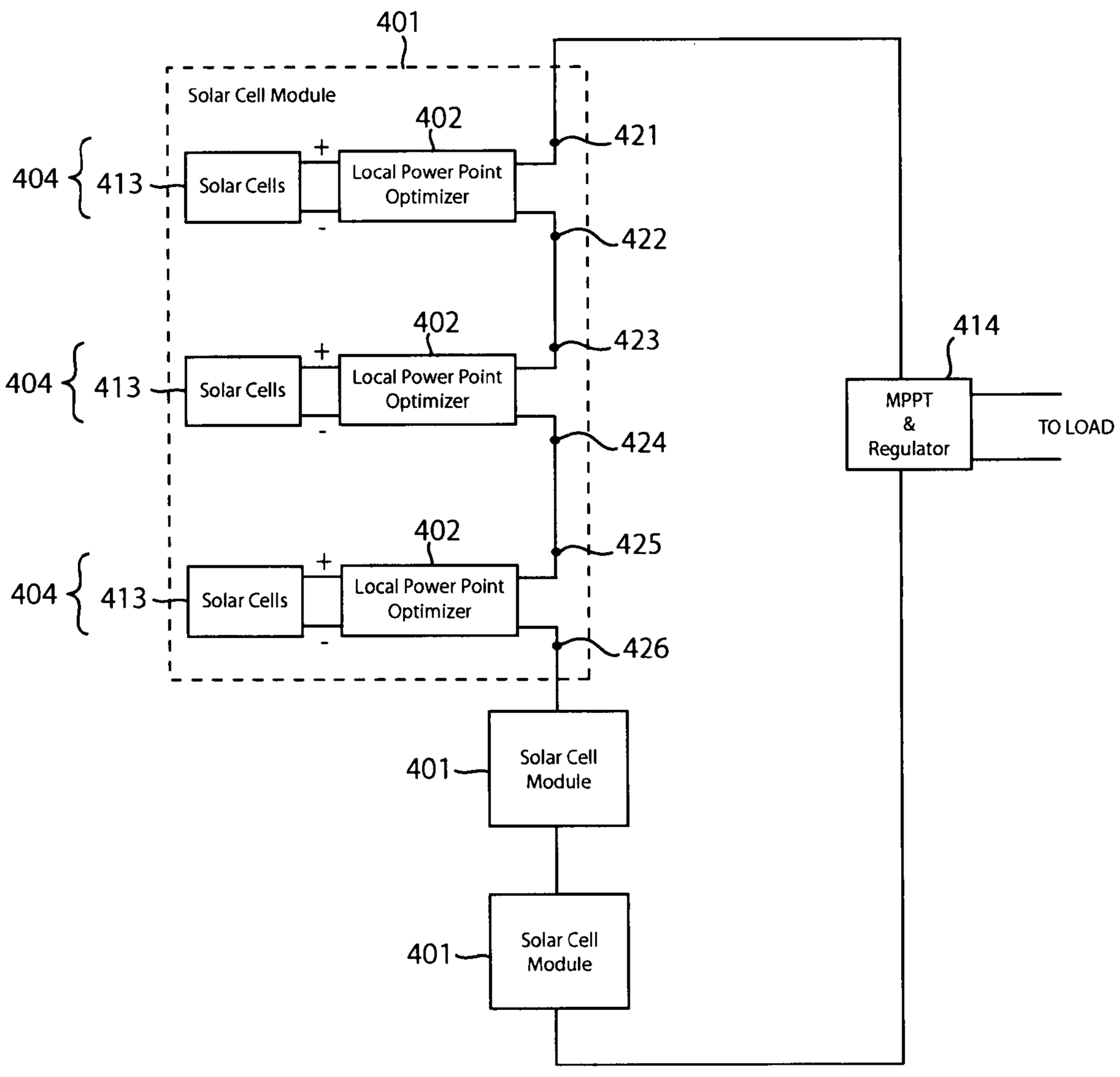
(57) **ABSTRACT**

In one embodiment, a solar cell installation includes several groups of solar cells. Each group of solar cells has a local power point optimizer configured to control power generation of the group. The local power point optimizer may be configured to determine an optimum operating condition for a corresponding group of solar cells. The local power point optimizer may adjust the operating condition of the group to the optimum operating condition by modulating a transistor, such as by pulse width modulation, to electrically connect and disconnect the group from the installation. The local power point optimizer may be used in conjunction with a global maximum power point tracking module.



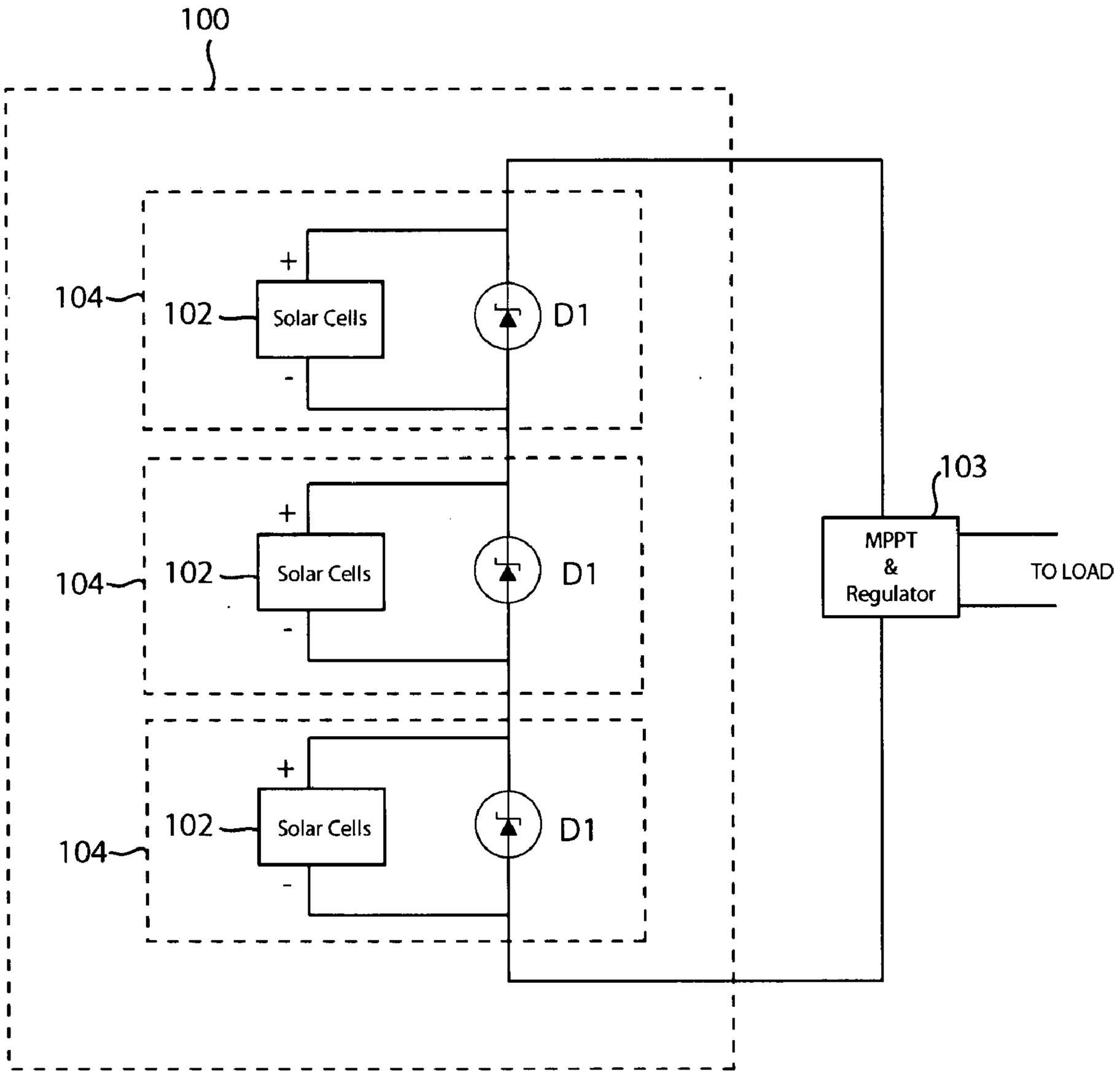


FIG. 1
(PRIOR ART)

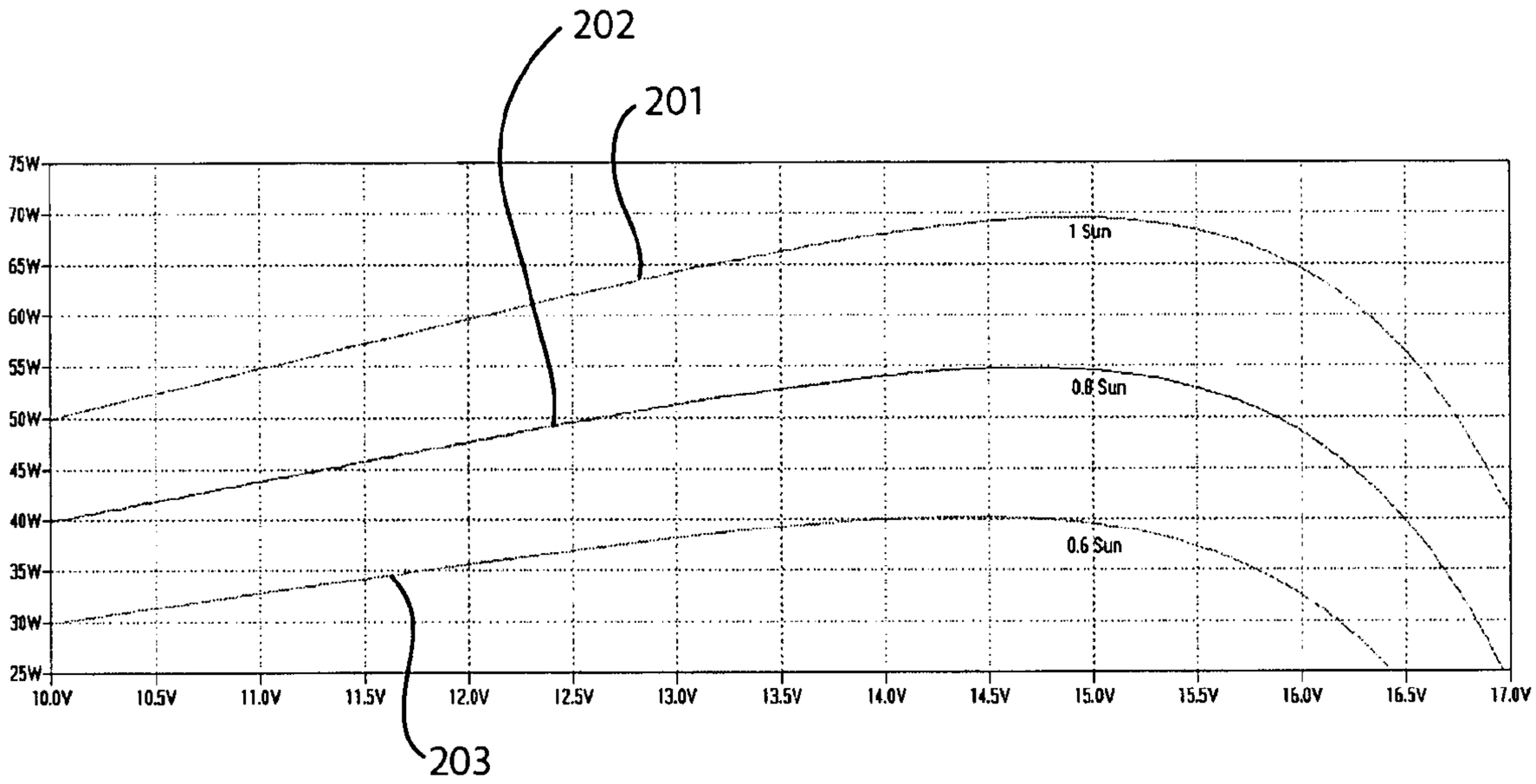

202
201
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W
1 Sun
0.8 Sun
0.6 Sun
10.0V
10.5V
11.0V
11.5V
12.0V
12.5V
13.0V
13.5V
14.0V
14.5V
15.0V
15.5V
16.0V
16.5V
17.0V
203

FIG. 2

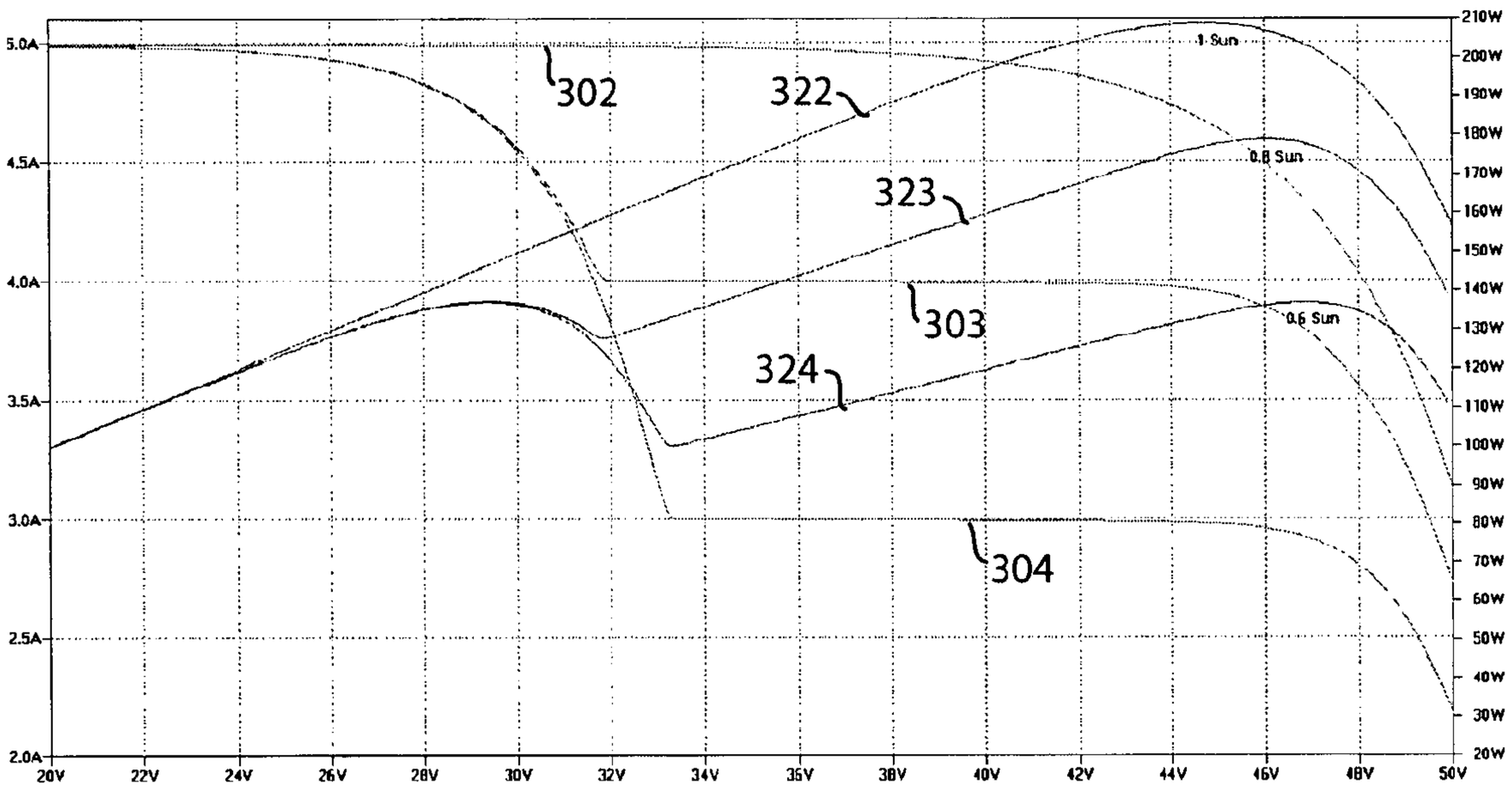

5.0A
4.5A
4.0A
3.5A
3.0A
2.5A
2.0A
210W
200W
190W
180W
170W
160W
150W
140W
130W
120W
110W
100W
90W
80W
70W
60W
50W
40W
30W
20W
1 Sun
0.8 Sun
0.6 Sun
20V
22V
24V
26V
28V
30V
32V
34V
36V
38V
40V
42V
44V
46V
48V
50V
302
322
323
303
324
304

FIG. 3

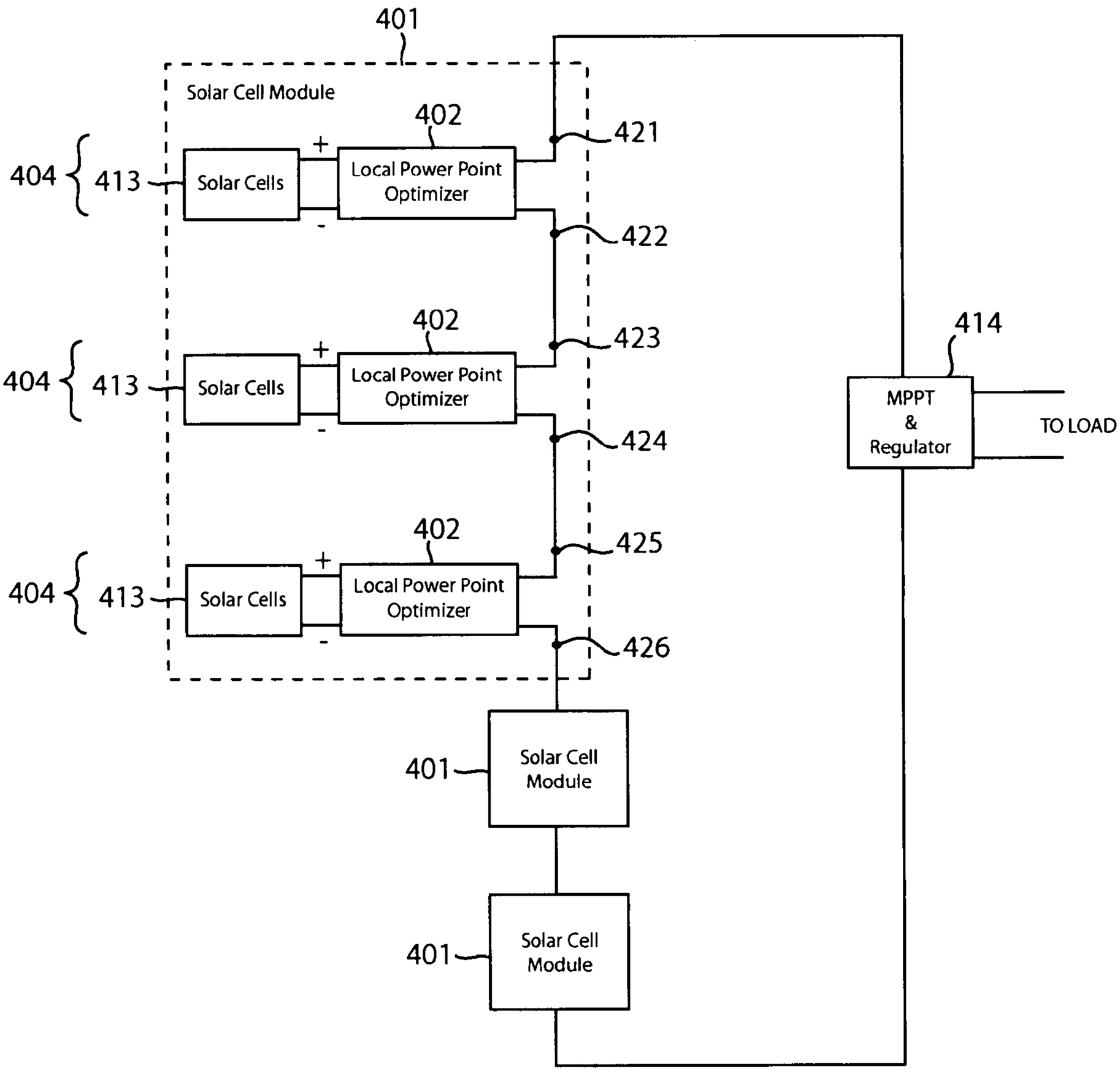

401
Solar Cell Module
402
421
404
413
Solar Cells
+
Local Power Point Optimizer
-
422
402
423
404
413
Solar Cells
+
Local Power Point Optimizer
-
424
402
425
404
413
Solar Cells
+
Local Power Point Optimizer
-
426
401
Solar Cell Module
414
MPPT & Regulator
TO LOAD
401
Solar Cell Module

FIG. 4

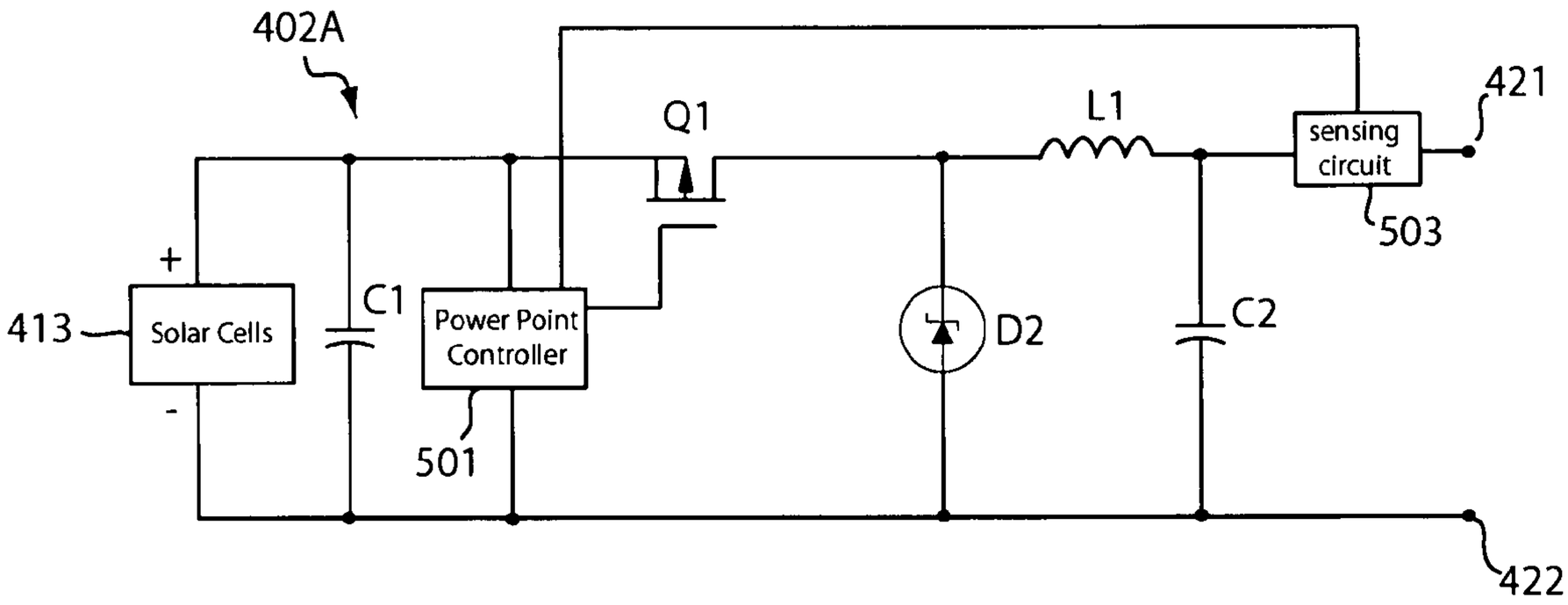

402A
Q1
L1
421
sensing circuit
503
+
413
Solar Cells
-
C1
Power Point Controller
501
D2
C2
422

FIG. 5

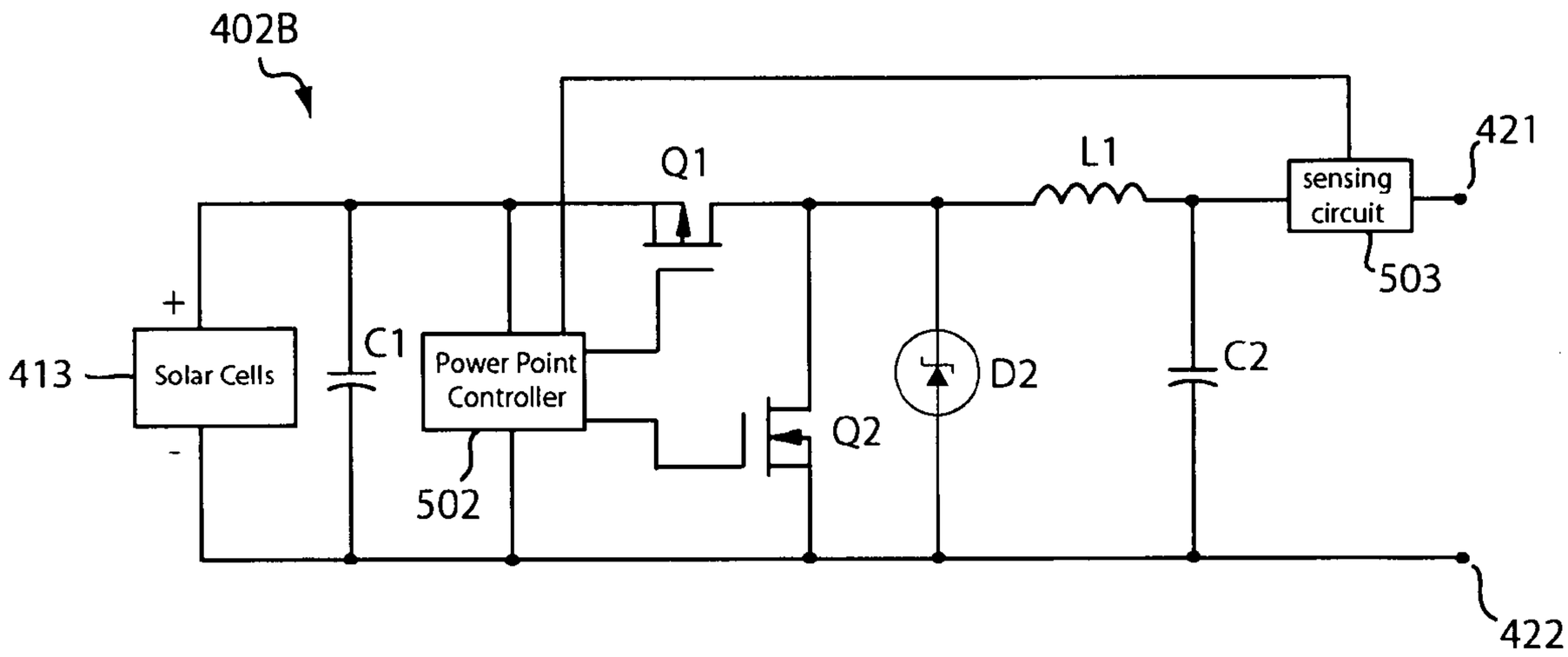

402B
Q1
L1
421
sensing circuit
503
+
413
Solar Cells
-
C1
Power Point Controller
502
Q2
D2
C2
422

FIG. 6

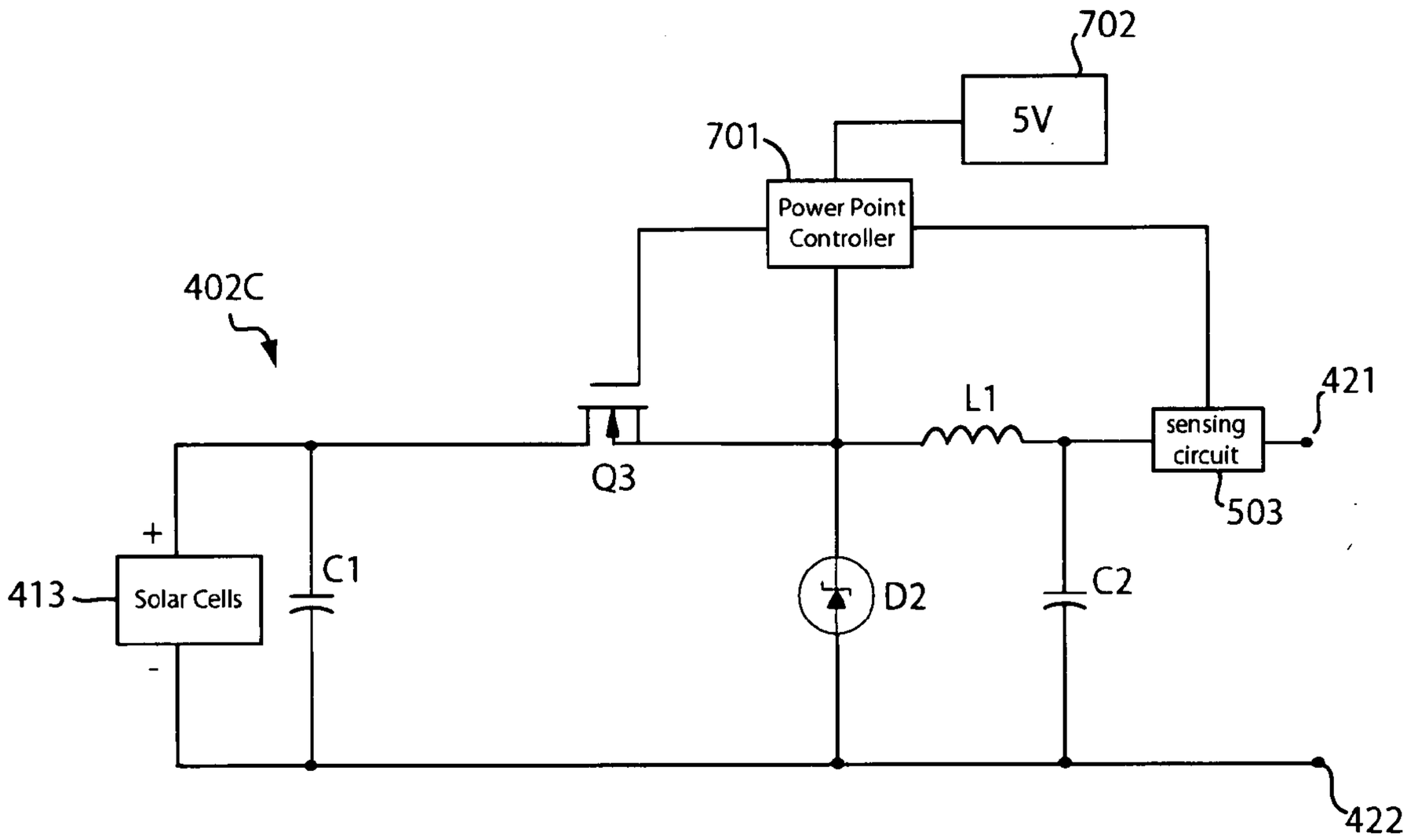

702
5V
701
Power Point Controller
402C
421
L1
sensing circuit
503
Q3
+
413
Solar Cells
-
C1
D2
C2
422

FIG. 7

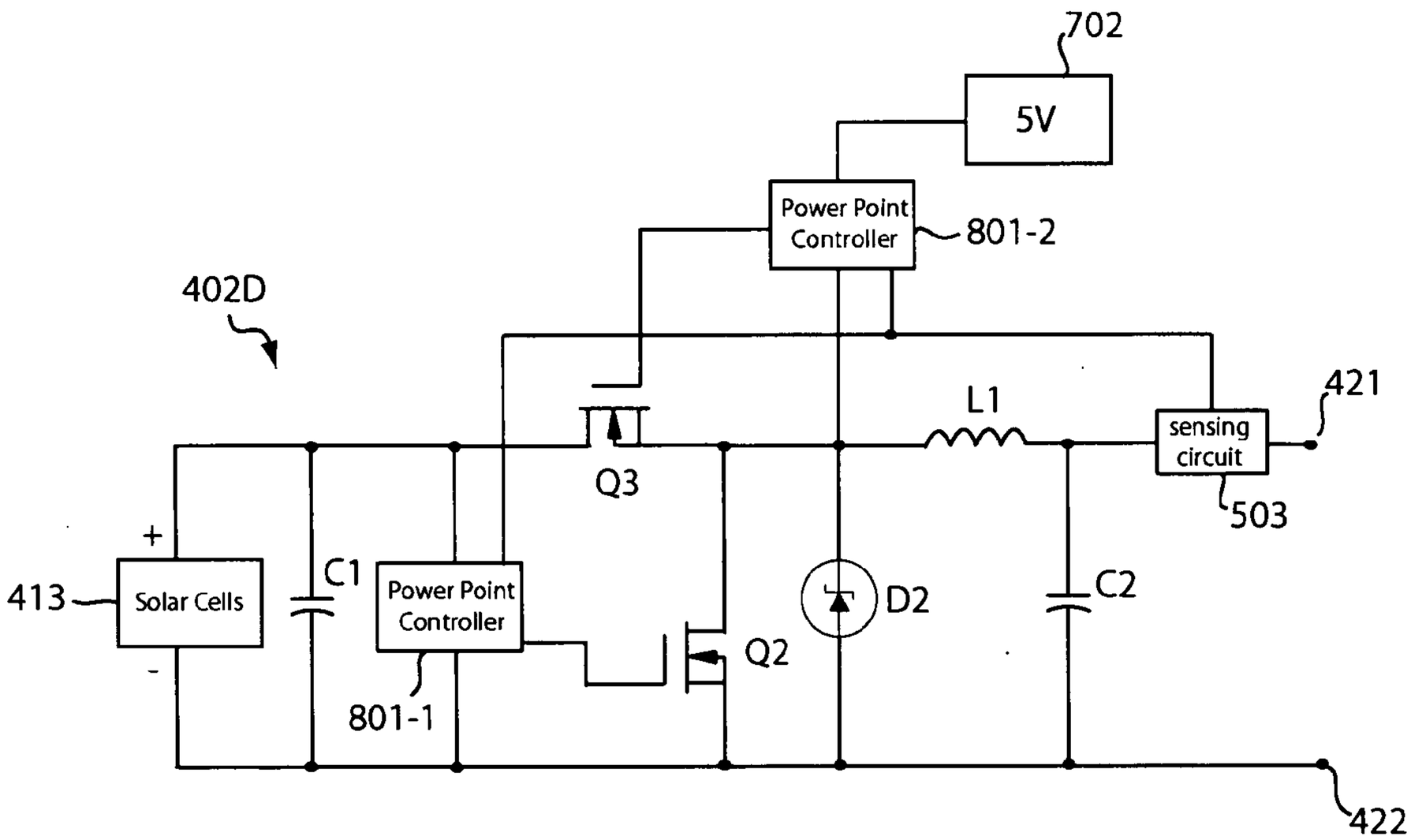

702
5V
Power Point Controller
801-2
402D
421
L1
sensing circuit
503
Q3
+
413
Solar Cells
-
C1
Power Point Controller
801-1
Q2
D2
C2
422

FIG. 8

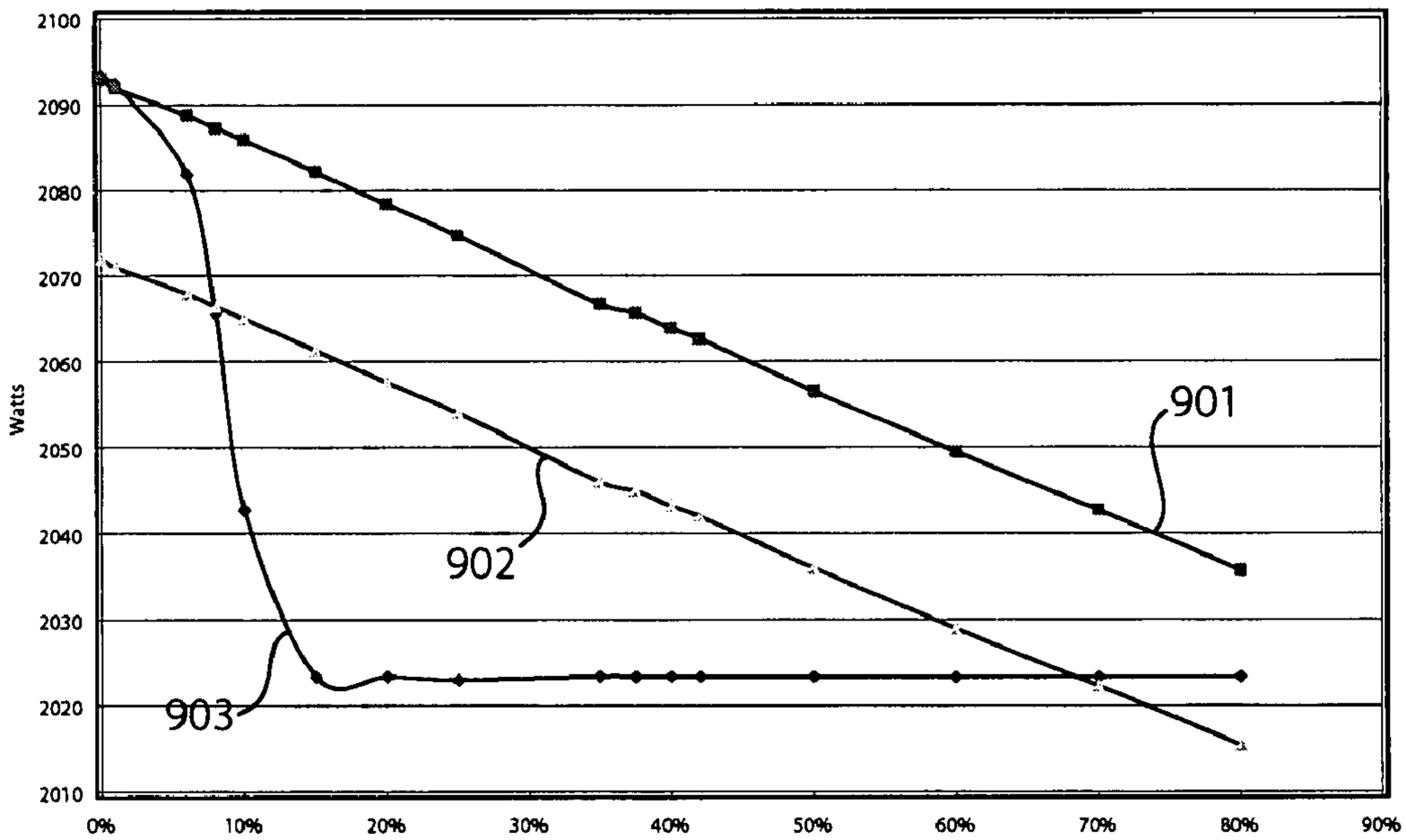

2100
2090
2080
2070
2060
2050
2040
2030
2020
2010
Watts
901
902
903
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
Performance Degradation in One String

FIG. 9

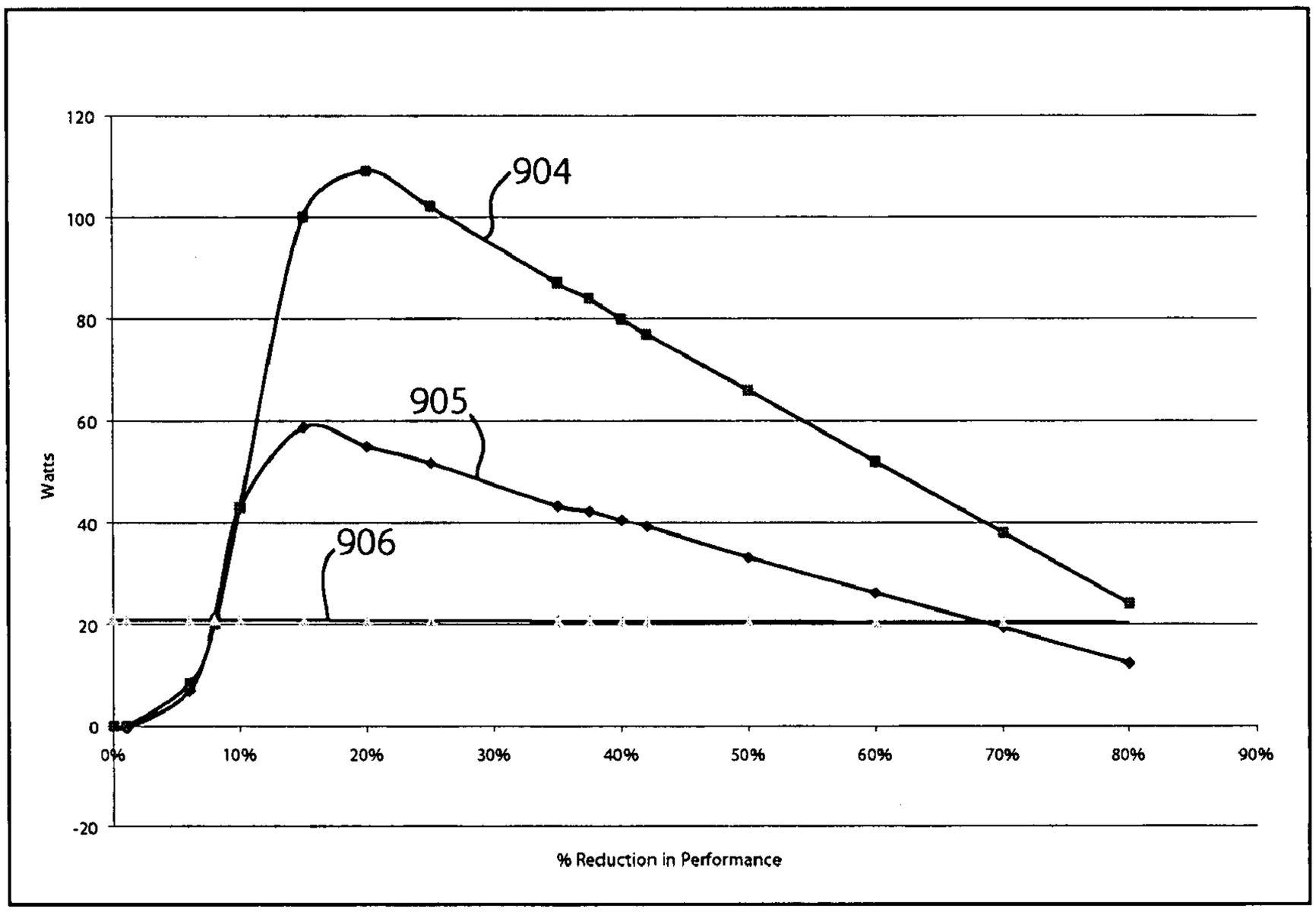

120
100
80
60
40
20
0
-20
Watts
904
905
906
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
% Reduction in Performance

FIG. 10

LOCALIZED POWER POINT OPTIMIZER FOR SOLAR CELL INSTALLATIONS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to solar cells, and more particularly but not exclusively to solar cell installations.

[0003] 2. Description of the Background Art

[0004] Solar cells are well known devices for converting solar radiation to electrical energy. They may be fabricated on a semiconductor wafer using semiconductor processing technology. Generally speaking, a solar cell may be fabricated by forming P-type and N-type diffusion regions in a silicon substrate. Solar radiation impinging on the solar cell creates electrons and holes that migrate to the diffusion regions, thereby creating voltage differentials between the diffusion regions. In a back-junction solar cell, both the diffusion regions and the metal grids coupled to them are on the back side of the solar cell. The metal grids allow an external electrical circuit to be coupled to and be powered by the solar cell.

[0005] A solar cell installation, such as that shown in FIG. **1**, typically includes a plurality of solar cells that are strung together to generate power delivered to a load, such as an inverter. In FIG. **1**, the installation includes a solar cell module **100** that comprises a plurality of solar cell strings **104**, each with a set of solar cells **102** and a diode D**1**. The installation may include more than one solar cell module. A maximum power point tracking and regulator module **103** optimizes the power delivered to the load on a global basis for the entire installation regardless of the number of solar cell modules employed.

[0006] Each set of solar cells **102** may comprise a plurality of solar cells arranged in serial fashion. Each diode D**1** allows for removal of a string **104** from the installation in the event the string **104** is faulty or drags down the overall power generation capability of the installation. During normal operation, a substring **104** generates power such that it has the polarity shown in FIG. **1**. In that case, the diode D**1** is reversed bias and has no electrical influence on the installation. In the event of a failure, a string **104** changes polarity such that its corresponding diode D**1** is forward biased, thereby shunting off that string **104** from the installation.

[0007] Although the installation of FIG. **1** and similar installations provide much needed renewable energy source, techniques for improving their power generation capability would make them more economically viable for widespread use.

SUMMARY

[0008] In one embodiment, a solar cell installation includes several groups of solar cells. Each group of solar cells has a local power point optimizer configured to control power generation of the group. The local power point optimizer may be configured to determine an optimum operating condition for a corresponding group of solar cells. The local power point optimizer may adjust the operating condition of the group to the optimum operating condition by modulating a transistor, such as by pulse width modulation, to electrically connect and disconnect the group from the installation. The local power point optimizer may be used in conjunction with a global maximum power point tracking module.

[0009] These and other features of the present invention will be readily apparent to persons of ordinary skill in the art upon reading the entirety of this disclosure, which includes the accompanying drawings and claims.

DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** schematically shows a conventional solar cell installation.

[0011] FIG. **2** shows a simulated response of a single string of solar cells operating at various illumination levels.

[0012] FIG. **3** shows a simulated response of three separate strings connected in series, with one string having various illumination levels.

[0013] FIG. **4** schematically shows a solar cell installation in accordance with an embodiment of the present invention.

[0014] FIGS. **5-8** schematically show a group of serially connected solar cells being used in conjunction with a local power point optimizer in accordance with embodiments of the present invention.

[0015] FIGS. **9** and **10** show simulated responses illustrating predicted performance of embodiments of the present invention.

[0016] The use of the same reference label in different drawings indicates the same or like components.

DETAILED DESCRIPTION

[0017] In the present disclosure, numerous specific details are provided, such as examples of apparatus, components, and methods, to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details. In other instances, well-known details are not shown or described to avoid obscuring aspects of the invention.

[0018] FIG. **2** shows a simulated response of a single string of twenty four solar cells operating at various illumination levels. In FIG. **2**, the vertical and horizontal axes represent the power and voltage outputs of the string, respectively. Plot **201** shows the response of the string at 1 sun of insolation. Plot **202** is for 0.8 sun of insolation and plot **203** is for 0.6 sun of insolation. The less than 1 sun of insolation in plots **202** and **203** may be attributable to dirt, clouds, shadows, etc. that block the sun from fully illuminating all of the solar cells in the string.

[0019] An installation, which in this case comprises a single string, is typically biased to generate a particular output voltage and current (i.e., power). The biasing point is also referred to herein as "operating condition." It can be seen from FIG. **2** that there is a particular bias point, referred to as "maximum power point," where the installation generates maximum output power. The power generated by the installation diminishes beyond the maximum power point.

[0020] FIG. **3** shows a simulated response of three separate strings connected in series, with each string having twenty four solar cells. In FIG. **3**, the horizontal axis represents output voltage. The left vertical axis represents output current and goes with plots **302-304**, while the right vertical axis represent output power and goes with plots **322-324**. In plots **302** and **322**, all three strings have the same 100% insolation. In plots **303** and **323**, two strings have 100% insolation and one string has 80% insolation. In plots **304** and **324**, two strings have 100% insolation and one string has 60% insolation.

[0021] Comparing FIGS. **2** and **3**, note that a decrease in solar radiation on a single string on a three-string installation (FIG. **3**) impacts the overall output power significantly more than in a single string installation (FIG. **2**). In the case of plots **303** and **323** where one string is illuminated with 80% sunlight (i.e., 0.8 sun) and the other two strings in full sunlight (i.e., 1 sun), the installation could provide 195 Watts but was providing only 179 Watts. This constitutes a 16 Watt loss in performance. The performance difference becomes more pronounced with more severe illumination reduction.

[0022] The present invention addresses these problems associated with partial illumination and solar cell performance variations in general by providing localized power point optimization. A local power point optimizer may be configured to manage power generation in each group of solar cells in an installation with several groups of solar cells such that the entire installation delivers optimum amount of power to the load. Embodiments of the present invention are now described beginning with FIG. **4**. It is to be noted that while the following embodiments describe buck conversion, other approaches, such as boost conversion, linear (continuous) shunting techniques, and AC power conversion, may also be used without detracting from the merits of the present invention.

[0023] FIG. **4** schematically shows a solar cell installation in accordance with an embodiment of the present invention. In the example of FIG. **4**, the installation includes one or more solar cell modules (also referred to as a "panel") **401**. Each solar cell module **401** may include a plurality of solar cells **413**, each of which may comprise a back-junction solar cell. The solar cells **413** may be connected in series to form a string. In the example of FIG. **4**, a string **404** includes a group of serially connected solar cells **413** and a local power point optimizer **402**.

[0024] A local power point optimizer **402** may comprise an electrical circuit configured to optimize the power contribution of a group of solar cells to a solar cell installation with several groups of solar cells. A local power point optimizer **402** may be configured to load a string of solar cells **413** at the point of maximum power delivery (i.e., maximum power point). Nodes **421-426** are shown in FIG. **4** for reference as to how a local power point optimizer **402** may be included in an installation.

[0025] The installation of FIG. **4** also includes a maximum power point tracking (MPPT) and regulator module **414**. The module **414** may comprise a commercially-available MPPT module for providing a global maximum power point tracking for the entire installation. The module **414** may be connected to an inverter of a residential home, commercial structure, or industrial facility, for example. As will be more apparent below, localized power point optimization in conjunction with global maximum power point tracking advantageously improves the performance of a solar cell installation.

[0026] FIG. **5** schematically shows a group of serially connected solar cells **413** being used in conjunction with a local power point optimizer **402**A in accordance with an embodiment of the present invention. Local power point optimizer **402**A is a particular embodiment of the local power point optimizer **402** shown in FIG. **4**. The local power point optimizer **402**A may be serially connected to the installation of FIG. **4** by way of nodes **421** and **422**, for example.

[0027] In one embodiment, the local power point optimizer **402**A comprises an electrical circuit configured to control the amount of power contributed by the serially connected solar cells **413** to the overall installation of solar cells. In the example of FIG. **5**, the local power point optimizer **402**A comprises a power point controller **501**, a P-channel metal oxide semiconductor field effect transistor (PFET) Q**1**, an output stage comprising an inductor L**1** and capacitor C**2**, a power reserve capacitor C**1**, a diode D**2**, and a sensing circuit **503**. The sensing circuit **503** may comprise a resistor, comparator, or other circuit arrangement or component configured to sense the current and voltage output of the string **404**.

[0028] The power point controller **501** may comprise electrical circuit configured to monitor the voltage and current output of the string **404** by way of the sensing circuit **503**, determine the maximum power point of the string, and control the switching of the transistor Q**1** to adjust the bias point of the string to the determined maximum power point. The power point controller **501** may employ conventional maximum power point tracking algorithm, such as the Hill-climbing or RCC algorithm, to track, and thereby determine, the maximum power point of the string.

[0029] In the example of FIG. **5**, the power point controller **501** loads the solar cells **413** to adjust the bias point of the string to the maximum power point. In one embodiment, the power point controller **501** does so by adjusting the duty cycle of a pulse width modulated signal used to control the switching of the PFET Q**1**. Turning ON the PFET Q**1** electrically connects the solar cells **413** to the rest of the solar cell installation. Conversely, turning OFF the PFET Q**1** electrically disconnects the solar cells **413** from the rest of the solar cell installation.

[0030] The power point controller **501** may be implemented using a microcontroller to perform maximum power point tracking and a buck regulator to control the loading of the string to adjust its power point to the maximum power point, for example. The power point controller **501** may switch ON the PFET Q**1** in situations where the solar cells **413** can generate voltage and/or current at the maximum power point, and switch OFF the PFET Q**1** in situations where the solar cells **413** cannot generate voltage and/or current at the maximum power point. The reserve capacitor C**1** stores charge from the solar cells **413** when the PFET Q**1** is OFF and discharges when the PFET Q**1** is ON. This allows the solar cells **413** together with charge stored in the reserve capacitor C**1** to deliver maximum power in situations where the solar cells **413** by themselves could not. The reserve capacitor C**1** thus advantageously increases the time when the solar cells **413** can be connected and thus contributes power to the installation.

[0031] As a particular example, assuming the load (e.g., inverter) requests 5 amps but the string can only provide a maximum of 4 amps due to a cloud cover or other reasons, the power point controller **501** will adjust the switching of the PFET Q**1** such that approximately 1 amp of current passes through the diode D**2**, bypassing the string. The net impact of this is that the string would still be providing the installation 4 amps, its maximum power point at that time, instead of being in a low-power generate state at higher current.

[0032] The diode D**2** provides a current path through the string when the PFET transistor is switched OFF. The diode D**2** also serves as a safety measure for shunting the solar cells **413** OFF the installation when the solar cells **413** reverse polarity, such as during very low power generation or failure.

The diode D2 is reversed biased, and therefore does not affect the operation of the string during normal operation, in that case.

[0033] The inductor L1 and capacitor C2 form an output stage for filtering the output of the string so that it provides a steady, rather than rapidly changing, voltage. It is to be noted that the inductor L1 and capacitor C2 are not needed in every string. To save cost and for improved efficiency, the inductor L1 and capacitor C2 may be limited to some, but not all, of the strings **404** of the installation of FIG. **4**. Depending on the application, the inductor L1 and capacitor C2 may also be omitted entirely from the installation.

[0034] Suitable values for a 5 Amp circuit are about 1 milli Farad for capacitors C1 and C2 and 10 micro Henry for inductor L1. The capacitors C1 and C2 preferably have a high ripple current capability (e.g., >5A) and low ESR. The inductor L1 preferably has low resistance and able to handle current greater than 6 Amps. The PFET Q1 preferably has as low ON resistance as possible (e.g., STP80 PF55 transistor from ST Microelectronics; 0.016 Ohms ON resistance). A suitable diode D2 includes the 80SQ045 diode from International Rectifier. The switching period of the PFET Q1 may be optimized based on selected components, but 10-100 kHz may be suitable depending on the application.

[0035] FIG. **6** schematically shows a group of serially connected solar cells **413** being used in conjunction with a local power point optimizer **402**B in accordance with another embodiment of the present invention. Local power point optimizer **402**B is a particular embodiment of the local power point optimizer **402** shown in FIG. **4**.

[0036] The local power point optimizer **402**B is the same as the local power point optimizer **402**A of FIG. **5** except for the addition of an N-channel metal oxide semiconductor field effect transistor (NFET) Q2. The NFET Q2 provides a low loss (compared to the diode D2) current path through the string when the PFET Q1 is OFF. The power point controllers **501** and **502** are the same except that the power point controller **502** synchronously switches the transistors Q1 and Q2, i.e., PFET Q1 is ON when NFET Q2 is OFF and vice versa. The diode D2 is an optional safety measure in the local power point optimizer **402**B. The diode D2 may be omitted in some applications. The components and operation of the power point optimizers **402**B and **402**A are otherwise the same.

The local power point optimizer **402**A has fewer components, and is thus cheaper to manufacture, than the local power point optimizer **402**B. However, the local power point optimizer **402**B is preferable in applications requiring higher efficiency. A limitation of both local power point optimizers **402**A and **402**B is that a P-channel MOSFET, such as PFET Q1, has a minimum resistance of about 0.02 Ohm when ON. This means that about 0.5 Watt is wasted by the inefficiency of the PFET. A higher cost but higher performance alternative is to use an NFET as a high side switch. However, employing an NFET as a high side switch would require a voltage source that is higher in voltage than the output voltage of some solar cell strings. This necessitates the use of an additional voltage source, such as a voltage source **702** shown in FIGS. **7** and **8**.

[0037] FIG. **7** schematically shows a group of serially connected solar cells **413** being used in conjunction with a local power point optimizer **402**C in accordance with another embodiment of the present invention. Local power point optimizer **402**C is a particular embodiment of the local power point optimizer **402** shown in FIG. **4**.

[0038] The local power point optimizer **402**C is the same as the local power point optimizer **402**A of FIG. **5** except for the use of an NFET Q3, rather than a PFET Q1. The NFET Q3 is coupled to a voltage source **702**, which allows for enough gate voltage to switch ON the NFET Q3. In one embodiment, the voltage source **702** provides approximately 5V. The voltage source **702** may be other strings in the solar cell installation, a voltage converter circuit (e.g., charge pump), a designated solar cell in a solar cell module, etc. The power point controllers **501** and **701** are the same except that the power point controller **701** provides additional voltage to the NFET Q3 to switch it ON. The components and operation of the local power point optimizers **402**A and **402**C are otherwise the same.

[0039] The local power point optimizer **402**D shown in FIG. **8** is a synchronous version of the local power point optimizer **402**C. A power point controller **801**, which is shown in two parts as controllers **801-1** and **801-2**, synchronously controls the NFET Q3 and NFET Q2 to adjust the bias point of the string as before. A voltage source **702** allows the power point controller **801** to apply enough voltage on the gate of the NFET Q3 to turn it ON.

[0040] The power point controller **801** operates the same way as the power point controller **501** except that the power point controller **801** synchronously controls an NFET Q3 and an NFET Q2. The NFET Q3 is switched OFF when the NFET Q2 is ON and vice versa. Like in the local power point optimizer **402**B of FIG. **6**, the NFET Q2 provides a low loss current path (compared to the diode D2) when the NFET Q3 is OFF. The diode D2 is an optional safety measure in the local power point optimizer **402**D. The diode D2 may be omitted in some applications. The components and operation of the power point optimizers **402**D and **402**A are otherwise the same. Suitable values for the local power point optimizer **402**D for a **5**A circuit are shown in Table 1.

TABLE 1

Component	Value	Loss information	Part #
C1	3900 uF, 25 V	16 mOhms @ 20 C	UPW1E392MHH Nichicon
C2	1000 uF, 25 V	32 mOhms @ 20 C	UPW1E102MPD Nichicon
Q3	IRF6678	3 mOhms, Qg = 43nC	International Rectifier
Q2	FDS6690ACT	12 mOhms, Qg = 9nC	Fairchild Semiconductor Synchronous FET
L1	~60–120 uH		Micrometals T130-53 or similar

[0041] FIG. **9** shows a simulated response of a test solar cell module with 30 strings, each string having twenty four solar cells. The vertical axis represents the maximum power output of the test module in Watts, while the horizontal axis represents the performance degradation of a single string in percent. In FIG. **9**, plot **903** is the response of the test module when using a single global maximum power point tracking for all 30 strings, with one of the strings being degraded. Plot **902** is the response of the test module when using a single global maximum power point tracking for all 30 strings, with one of the strings being degraded, and a local power point optimizer **402**B (see FIG. **6**) for each of the strings. Plot **902** assumes 99% efficient local power point optimizers **402**B. Plot **901** is the same as plot **902** in the ideal case, which is 100% efficient local power point optimizers **402**B.

[0042] As can be seen in FIG. **9**, for a single string degradation in excess of approximately 8%, a conventional maximum power point tracking approach (plot **903**) does not recover the maximum power available from the test module. In fact, when the individual string has a reduction in performance in excess of approximately 15%, the conventional approach utilizes the overall test module at a bias point where the degraded string provides zero power. In contrast, local power point optimization (plots **902** and **901**) ensures that all strings in the test module always provide power to the load, independent of how degraded their performance might be relative to others. As a point of reference, 100% efficient local power point optimization (plot **901**), the ideal case, ensures that the safety diodes (e.g., diodes D**2**) are never forward biased.

[0043] FIG. **10** shows a simulated response of the test solar cell module with 30 strings, each string having twenty four solar cells. The vertical axis represents the recoverable power of the test module in Watts, while the horizontal axis represents the performance degradation of two strings in percent. In FIG. **9**, plot **906** is the response of the test module when using a single global maximum power point tracking for all 30 strings, with two of the strings being degraded. Plot **905** is the response of the test module when using a single global maximum power point tracking for all 30 strings, with two of the strings being degraded, and a local power point optimizer **402**B for each of the strings. Plot **905** assumes 99% efficient local power point optimizers **402**B. Plot **906** is the same as plot **905** in the ideal case, which is 100% efficient local power point optimizers **402**B.

[0044] As can be seen from FIG. **10**, for performance reduction of 20% in two of the thirty strings in the test module, 99% efficient local power point optimization (plot **905**) can extract 90W (110W-20W) more from the test module compared to the conventional approach (plot **906**).

[0045] While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure.

What is claimed is:

1. A solar cell installation comprising:

a plurality of groups of solar cells, the plurality of groups of solar cells being interconnected to generate an overall output power to a load; and

a separate local power point optimizer for each group of solar cells in the plurality of groups of solar cells, the local power point optimizer including a power point controller configured to modulate a first transistor to electrically connect and disconnect a corresponding group of solar cells to the installation to adjust a bias point of the corresponding group of solar cells to deliver maximum power as determined by the local power point optimizer.

2. The solar cell installation of claim **1** wherein the local power point optimizer synchronously controls the first transistor and a second transistor to adjust the bias point of the corresponding group of solar cells, the second transistor providing a current path through the corresponding group of solar cells when the first transistor is switched OFF.

3. The solar cell installation of claim **2** wherein the first transistor comprises a PFET and the second transistor comprises an NFET.

4. The solar cell installation of claim **1** further comprising a maximum power point tracking module configured to adjust an operating point of the plurality of group of solar cells to maximize the overall output power to the load as determined by the maximum power point tracking module.

5. The solar cell installation of claim **1** further comprising an output stage configured to filter a voltage output of the corresponding group of solar cells.

6. The solar cell installation of claim **1** wherein the output stage comprises an inductor having a first end and a second end and a capacitor having a first end and a second end, the first end of the inductor being coupled to the first transistor, the second end of the inductor being coupled to a first end of the capacitor, the second end of the capacitor being coupled to another local power point optimizer of another group of solar cells in the plurality of solar cells.

7. The solar cell installation of claim **1** wherein the first transistor comprises a PFET.

8. The solar cell installation of claim **1** wherein the first transistor comprises an NFET.

9. The solar cell installation of claim **8** further comprising a voltage source configured to provide additional voltage to a gate of the first transistor to allow the first transistor to be switched ON.

10. The solar cell installation of claim **1** further comprising a diode across the corresponding group of solar cells, the diode being configured to be reversed bias during normal operation of the corresponding group of solar cells.

11. The solar cell installation of claim **1** further comprising a capacitor configured to be charged by the corresponding group of solar cells when the first transistor is switched OFF.

12. A method of controlling power generation of solar cells in a solar cell installation, the method comprising:

(a) providing a plurality of groups of solar cells; and

(b) for each group of solar cells in the plurality of groups of solar cells:

(i) determining an operating condition of the group of solar cells where the group of solar cells generates a particular amount of power; and

(ii) controlling an amount of time the group of solar cells contributes power to the plurality of groups of solar cells based on the determined operating condition.

13. The method of claim **12** wherein the determined operating condition comprises a voltage and current output of the group of solar cells where the group of solar cells generates maximum power.

14. The method of claim **12** wherein controlling the amount of time the group of solar cells contributes power to the plurality of groups of solar cells comprises:

modulating a first transistor to connect and disconnect the group of solar cells to the installation.

15. The method of claim **12** wherein controlling the amount of time the group of solar cells contributes power to the plurality of groups of solar cells comprises:

synchronously switching a first transistor and a second transistor to connect and disconnect the group of solar cells to the installation.

16. A solar cell installation comprising:

a plurality of groups of solar cells;

an electrical circuit in each group of solar cells in the plurality of group of solar cells, the electrical circuit being configured to determine an operating condition of a corresponding group of solar cells where the corresponding group of solar cells generates a target power

output and to adjust the corresponding group of solar cells to operate at the determined operating condition.

17. The solar cell installation of claim **16** wherein the electrical circuit modulates a first transistor to electrically connect and disconnect the corresponding group of solar cells from the installation such that the corresponding group of solar cells generates the target power output.

18. The solar cell installation of claim **17** wherein the electrical circuit synchronously switches the first transistor and a second transistor to electrically connect and disconnect the corresponding group of solar cells from the installation such that the corresponding group of solar cells generates the target power output.

19. The solar cell installation of claim **18** wherein the first transistor comprises a PFET and the second transistor comprises an NFET.

20. The solar cell installation of claim **17** wherein the first transistor comprises an NFET.

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